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The Relationship Between Lower Extremity Strength and Shoulder Overuse Symptoms: A Model Based on Polio Survivors

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ABSTRACT

Objective: To determine the relationship between lower extremity weakness and shoulder overuse symptoms among polio survivors. We predicted that individuals with moderate weakness in their leg extensor muscles use their arms to help compensate for this weakness and would be at high risk for developing symptoms of shoulder overuse.

Design: A cohort study of polio survivors recruited from the Einstein-Moss Post-Polio Management Program, the community and the surrounding tri-state area.

Setting: A research laboratory at Moss Rehabilitation Research Institute.

Participants: One hundred ninety-four polio survivors were studied; demographic and medical history data, symptom data, and strength data were obtained for each.

Main Outcome Measures: Presence or absence of shoulder symptoms and ratings of pain by visual analogue scale (VAS) were recorded. Strength was measured using a hand-held dynamometer and manual muscle testing (MMT).

Results: Shoulder symptoms could be grouped into two distinct clusters based on the type of testing used for assessment. Symptoms elicited by palpation were present in 26% of the subjects and were strongly related to knee extensor strength and weight. These symptoms were more common among females than males (42% vs. 10%). Symptoms elicited by resistance tests were present in 33% of the subjects and were seen with equal frequency in both genders. These symptoms were also related to lower extremity strength, however the specific relationship was not as clear as for the palpation-related symptoms.

Conclusions: Lower extremity weakness predisposes individuals to shoulder overuse symptoms. Gender and body weight are contributing factors. These results may generalize to other populations with lower extremity weakness, including the elderly.

INTRODUCTION

The relationship between muscle weakness, overuse and injury is thought to be both a cyclical and a reciprocal one. Muscle weakness can produce overuse, overuse can lead to further weakness, and both can predispose to injury.[1] Overuse can occur directly when weakened muscles need to work harder to maintain a certain force or indirectly when alternate muscles are recruited to compensate for weak ones. Individuals can enter this weakness--overuse--injury cycle at different points and at different levels of weakness.

There are various etiologies of muscle weakness, but each may lead to overuse. Muscle weakness can occur as a result of lack of exercise (disuse), after an injury or illness, or as the result of a disease, such as polio. The resulting muscle weakness may be severe or mild. Often, individuals may not even be aware of mild muscle weakness. They may function and feel normal during their daily activities but might actually be overusing muscles to compensate for undetected "subclinical" weakness.

Because the muscle weakness experienced by many polio survivors is often quite significant, this population is susceptible to an accelerated pattern of overuse. Theoretically, this would allow the symptoms of overuse to be readily observed in a small population over a short period of time. For this reason, we hypothesize that the post-polio population provides an excellent model for the study of overuse disorders in the general population.

There are over one million polio survivors in the United States.[2] After recovering from the acute infection, survivors were left with varying degrees of muscle strength. As time passed, they became very adept at compensating for weakened muscles, with the end result being a higher risk of overuse and trauma to the compensating muscles as well as those muscles weakened by the initial polio.

Although the muscle weakness of the polio survivor is often more pronounced than that noted in the general population, polio is not a primary muscle disease. Normal muscle physiology, sensation and motor control are preserved.[3] It is thus a "pure" model for studying the effects of muscle weakness on the remainder of the musculoskeletal system.

Polio affected the lower extremities with twice the frequency of the upper extremities.[4] As a result, the most common complaints of polio survivors are related to issues of mobility.[5] For example, individuals with knee or hip extensor weakness may have difficulty with activities like climbing stairs or rising from a chair and often use their arms to assist with weight-bearing (e.g. to push off the armrests of a chair or pull up on a stair railing). We hypothesized that this behavior would lead to increased susceptibility to shoulder overuse and there would be an association between leg extensor weakness and shoulder overuse symptoms.

Previous studies have looked at the relationship of lower extremity weakness to various gait parameters and overuse of compensatory muscles in the legs among polio survivors.[3,6] There have also been studies on upper extremity overuse in individuals with paraplegia who must rely exclusively on their upper extremities for mobility.[7,8] However, to date, there have not been any studies which explored the potential relationship between lower extremity weakness and upper extremity overuse in an ambulatory population.

Therefore, the objective of this study was to explore the relationship between lower extremity weakness and upper extremity overuse among polio survivors, focusing specifically on shoulder symptoms and leg extensor strength. We predicted a curvilinear relationship between symptoms and strength (i.e. that the proportion of subjects with shoulder symptoms would be highest in the mid-range of leg extensor strength). These individuals would be more active than those with severe weakness and would put more stress on their arms during everyday activities

than those with mild or no noticeable weakness. We also predicted that shoulder symptoms would increase with age, weight and activity level and that the duration of time since the original polio infection would also be an important factor.

METHOD

Subjects

A total of 290 polio survivors were recruited from the Einstein-Moss Post-Polio Management Program and the community at large, including the surrounding four-state area: Pennsylvania, New Jersey, Delaware, and southern New York. The inclusion criteria were as follows: 1) a history of polio, 2) no major disabilities unrelated to polio that could cause weakness or overuse problems (e.g. stroke, amputation, inflammatory arthritis, peripheral neuropathy, muscular dystrophy, or congenital malformation), 3) no serious illnesses such as heart or lung disease which would make it unsafe for them to exert themselves in a strength test (e.g. severe emphysema, poorly controlled asthma, resting angina, recent heart attack, or recent treatment of an uncontrolled heart condition), and 4) no fractures or surgeries within the previous six months.

Of the 290 polio survivors initially screened, 194 participated in the study. Thirty-one individuals were excluded because they did not meet the inclusion criteria. The remaining 65 individuals did not participate because of personal reasons (transportation problems, job conflicts, illness/death in family, etc.) or simply did not show up for one or more scheduled appointments. Ultimately, 98 men and 96 women were enrolled in the study. All subjects provided written informed consent prior to testing.

Procedure

The following protocol was approved by our Institutional Review Board. A brief clinical interview was conducted to review a standardized medical history questionnaire and a polio history form in which subjects specified their age at the time of the initial polio infection and identified any sites where they were left with residual weakness or paralysis. There were seven possible sites given: neck, back, abdomen, left arm, left leg, right arm, and right leg.

Each subject also completed a self-administered activity assessment survey, which was developed based on a questionnaire designed to measure habitual physical activity.[9] The survey included specific activities that might predispose to overuse symptoms and were divided into household, occupational, and recreational tasks. Under each heading, the tasks were broken down into upper limb activities (e.g. reaching, typing, sewing), lower limb activities (e.g. standing, walking, climbing stairs) and transfer activities (moving from sit to stand). For each activity, the subjects chose one of four levels that gave the best estimate of the frequency with which they performed that activity. Upper limb, lower limb, and transfer activity levels were then calculated by summing the frequency scores in each category.

After the forms were completed, height (cm) and weight (kg) were measured using a standard scale. A nurse then performed a symptom assessment, which included a combination of palpation and resistance tests of the biceps and supraspinatus. For the biceps palpation test, the shoulder was in neutral rotation, the elbow flexed at 90 degrees and the forearm supinated. Pressure was applied in the bicipital groove on the anterior shoulder. The arm was positioned in a similar way for the biceps resistance test, except the palm was down. The nurse then attempted to supinate the forearm while the subject resisted. For the supraspinatus palpation test, the arm was relaxed at the side and pressure was then applied on the tendon insertion site, just proximal

to the greater tuberosity of the humerus. Finally, for the supraspinatus resistance (impingement) test, the arm was held straight out at the side with the thumb pointing towards the floor. The nurse pushed on the arm above the elbow while the subject resisted.

If subjects reported feeling shoulder pain during a symptom test, they were asked if they had experienced pain in that area before and if they could identify the estimated date of onset (EDO) of the pain. They were also asked to specify activities that caused pain in the same area. Pain or tenderness identified as being related to the exam only (i.e. "It only hurts when you push there.") was not considered a potential overuse symptom and was not included in any of the analyses.

A manual strength examination was then performed by a physical therapist using a hand-held dynamometer (Empi Microfet2, St. Paul, MN). The physical therapist was masked from the results of the symptom assessment to prevent any potential bias. The bilateral hip extensor and knee extensor muscle groups were tested in gravity-eliminated postures. Bilateral shoulder flexion and abduction strength was also measured to account for the possibility that shoulder symptoms might be related to shoulder rather than leg weakness. The postures, placement of the dynamometer, and stabilization points were standardized (Table 1), along with the verbal encouragement used during the testing.

For each strength test, the subject pushed against the padded dynamometer force plate, which the physical therapist held stationary. The peak force was measured in pounds, and the range of the dynamometer was 0 to 100 lbs. Two measurements of peak force were taken for each muscle group. Additional measurements were taken only if the first two varied by more than 10% or by more than 1 lb. for strengths less than 10 lbs. The maximum number of

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Insert Table 1 about here.

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measurements for a single muscle group was four to prevent fatigue. If a subject reported pain during testing, those trials were considered invalid. For each muscle group, the average of the valid trials was used for analysis. However, any muscle groups that did not have two trials that met the 10% or 1lb. criteria after four attempts were not included in any analyses.

In order for individuals to use their arms effectively to help push themselves out of a chair, they must have gravity-resistant strength in their elbow extensor muscles. Therefore, once the dynamometer testing was completed, the physical therapist performed manual muscle testing (MMT) on both elbow extensors using a standardized protocol as described by Kendall, and the Lovett grading system.[10,11] If the strength was equal to or greater than grade 3, it was specified using a plus (+) or a minus (-) sign to designate intermediary levels. If the strength was less than a grade 3, a muscle grade of <3 was recorded. Only subjects who had a minimum of grade 3 strength in both elbow extensors were included in the symptom and strength analyses

Reliability

Two nurses and three physical therapists were involved in data collection for this study. Therefore, it was necessary to get a measure of inter-rater reliability for both the symptom and strength assessments.

Sixteen polio survivors were tested to determine symptom interrater reliability. Nurse #1 performed the initial assessment for 10 of the subjects and Nurse #2 performed the initial assessment for the remaining 6 subjects. A period of one to five days separated the two

assessments for each subject. All assessments were done at the same time of day. . For symptom reliability, p_o or the proportion of observed agreement was calculated by taking the number of assessments when both nurses agreed divided by the total number of assessments for each of the four symptom tests. All values for p_o were above 93% except for the supraspinatus (impingement) test, which was 87%.

To determine the interrater reliability of the strength measurements, six subjects (2 polio survivors and 4 individuals with no history of polio) had their hip extensor, knee extensor, shoulder flexion, and shoulder abduction strength tested bilaterally by each of the three physical therapists. For each subject, all strength assessments were performed at the same time of day within a one month period. Intraclass correlation coefficients (ICC[3,1][12]) were used as indices of reliability for the strength measurements. All ICC values were above 0.910 except hip extension on the dominant side, which was 0.787

Statistical Analysis

Data were analyzed using the SYSTAT7 software package. Subjects were classified based on whether they had a positive or negative response to each symptom test. In order to determine whether certain symptom tests were linked in their occurrence either by structure (biceps vs. supraspinatus) or type of test (palpation vs. resistance test), a correspondence analysis was performed. The results revealed two distinct clusters that were arbitrarily identified as Cluster 1 and Cluster 2. Subjects were then reclassified based on whether or not they had any Cluster 1 or Cluster 2 symptoms.

Biomechanically, there was no reason to believe that the symmetric/assymmetric use of the lower extremities was relevant to the production of shoulder symptoms. The knee extensors

work together to help lift a person off a chair, and the hip extensors work together to help the body straighten to a standing position. Therefore, we felt it was appropriate to consider combinations of the strengths of similar types of muscles in our analyses, including KNEES (the combined strength of both knee extensors), HIPS (the combined strength of both hip extensors), and ALL (the combined strength of both knee extensors and both hip extensors).

In order to determine the nature of the relationship between symptom status and the various independent variables (age, time since polio, weight, activity scores and the various strength measures), we converted the independent variables to quintiles (i.e. sorted each from smallest to largest and separated them into five bins with approximately the same number of subjects in each bin). The proportion of subjects in each quintile with either Cluster 1 or Cluster 2 symptoms was then calculated. Plots of the proportion of subjects in each symptom cluster against the various independent variables (in quintiles) revealed neither a linear pattern nor a good fit to a polynomial equation. Therefore, the quintiles were treated as categorical variables (1-5). The only exception was weight. In the plot of the proportion of subjects with Cluster 1 symptoms versus weight, we observed an increasing pattern. Therefore, this variable was treated as quantitative instead of categorical in the analyses for this symptom cluster. A Chi-square analysis was used to evaluate the effect of gender.

Because of the relatively large number of potential predictor variables, univariate logistic regression was performed to eliminate some terms prior to doing a multivariate stepwise logistic analysis. A cutoff value of 0.15 was used. In the multivariate analysis, the p-values were calculated relative to the highest level or quintile 5 for each independent variable. Odds ratios were calculated as a measure of the difference in the proportion of shoulder symptoms between quintile 5 and the other quintiles.

RESULTS

Subject Characteristics

The range in age for the study population was 32 to 81 years (mean age: 57 $\pm$ 10 yr.). The median age at onset of polio was 5 years, and the median number of years since polio was 48, ranging from 29 to 80 years. As expected, the most common sites for residual weakness were the legs (left (57%) and right (55%)). All of the remaining sites had values below 25%. Approximately 7% of the subjects stated that they had no residual weakness or paralysis.

A total of 15 (8%) of the subjects enrolled in the study did not meet the minimum requirements for elbow extensor strength (grade 3 or better in both arms). Therefore, their data were excluded from the strength and symptom analyses.

Shoulder Symptoms

Overall, 90 (46%) of the subjects had one or more shoulder symptoms. The correspondence analysis showed that there were two distinct symptom clusters. Cluster 1 consisted of the four palpation tests (left and right biceps palpation and left and right supraspinatus palpation). Cluster 2 consisted of the four resistance tests (left and right supraspinatus (impingement) tests and left and right biceps tests). Replication of the correspondence analysis separately for each gender gave similar results. In both cases, the palpation-provoked symptoms formed one cluster and the resistance-provoked symptoms formed another.

There was no significant association between symptom clusters (Chi-square value = 0.060, 1 d.f., p = 0.806). Overall, 30 (17%) subjects had palpation-provoked symptoms only, 43

(24%) subjects had resistance-provoked symptoms only, and 17 (9%) subjects had both types of symptoms.

Palpation Symptom Analysis

There was a significant association between gender and the presence of palpation symptoms (Chi-square value = 15.552, 1 d.f., p-value < 0.001). A total of 38 (42%) females had palpation symptoms compared to only 9 (10%) males. Because of the relatively low number of males with these symptoms, the remaining analyses were performed with females only.

The results of the univariate logistic regression analysis with presence or absence of palpation symptoms as the dependent variable, showed that weight, age, shoulder flexion strength, upper limb activity score, KNEES and ALL had p-values below the 0.15 cutoff. When these variables were put into a stepwise multivariate logistic regression analysis, the results showed that KNEES and weight were the best predictors of the presence of palpation symptoms among females. The p-values and odds ratios for the model are listed in Table 2.

A plot of the proportion of females with palpation symptoms versus KNEES (in quintiles) showed evidence of a threshold effect (Figure 1). The proportion of females with palpation symptoms was significantly higher when bilateral knee extensor strength was less than 79 lb. than when it was greater than 79 lb. A plot of the proportion of females with palpation symptoms versus weight (in quintiles) revealed that as weight increased, the proportion of females with shoulder symptoms also increased (Figure 2).

Insert Table 2 about here.

Insert Figure 1 about here.

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Resistance Symptom Analysis

A Chi-square analysis showed no significant association between gender and presence of resistance symptoms (Chi-square value = 0.025, p = 0.999), with an approximately equal proportion of symptomatic subjects for each gender (males: 33% and females: 34%). Therefore, we initially performed the logistic analyses with both genders combined.

The results of the univariate analysis, with presence or absence of resistance symptoms as the dependent variable, showed that HIPS, KNEES, ALL, and age all had p-values that were less than the cutoff level of 0.15. The results of the stepwise multivariate analysis showed that the model containing ALL and age best predicted the presence of resistance symptoms. The p-values and odds ratios for the model are summarized in Table 3.

A plot of the proportion of subjects with resistance symptoms versus ALL (in quintiles) showed that the highest proportion of symptomatic subjects was found in the mid-range for overall leg extensor strength (Figure 3). The plot of the proportion of subjects with resistance

Insert Table 3 about here.

symptoms versus age (in quintiles) showed that subjects between the ages of 50 and 54 years, had the highest proportion of symptoms (Figure 4).

Because of concern that gender was possibly confounding the results, the analysis was repeated on each gender separately. The results of the univariate analysis for males showed that KNEES and age were the only predictors with p-values less than 0.15. The stepwise multivariate analysis resulted in a model containing both variables. Plots of the proportion of males with resistance symptoms revealed that the highest proportion of symptomatic males were in the mid-range for both bilateral knee extensor strength and age. For females, the results of the univariate analysis showed that HIPS, ALL, and age had p-values less than 0.15. The stepwise multivariate analysis produced a model containing HIPS and age. The highest proportion of symptomatic females was on the low end for both bilateral hip extensor strength and age.

The odds ratios, sensitivity, and specificity values for the KNEES model and the HIPS model for both genders were compared (Table 4). For males, the KNEES model appeared to be the best predictor, with larger, more significant odds ratios and a higher sensitivity value model than the HIPS model. However, the HIPS model for males had a higher value for specificity than the KNEES model. For females, the odds ratios for both the knee and hip models show similar patterns, and the sensitivity and specificity values for both models are comparable.

Insert Figure 3 about here.

Insert Figure 4 about here.

Insert Table 4 about here.

DISCUSSION

The purpose of this study was to determine if there was a systematic relationship between leg extensor weakness and the presence of pain potentially attributable to shoulder overuse. The results showed that the shoulder symptom tests could be divided into two distinct clusters based on the type of testing used for assessment. The results of the multivariate analyses appear to support the theory that these are two different symptom complexes.

Palpation-provoked symptoms were more common among females, as are many overuse injuries.[13,14] This may be due to differences in pain perception and report. Previous studies have suggested men have a higher pain tolerance than women, especially in tests involving pressure pain.[15,16,17] These differences in pain sensitivity have been attributed to a variety of factors including differences in body size and skin thickness, sex-role expectations, and hormones. This may explain why we did not see a significant gender effect for resistance symptoms, which were assessed with an active motion test as opposed to someone applying pressure to a particular area. In order to determine if gender differences might simply be related to greater stoicism among men, we assessed the severity ratings for the resistance symptoms and found no significant differences (i.e.women did not rate their pain intensity higher than men).

Palpation symptoms among women were strongly related to knee extensor strength and weight. The most likely explanation is that weak knee extensors cause increased demand on the arms during tasks such as getting up from a chair or using an assistive device for ambulation. Increased weight will also result in an increased demand on the arms during similar tasks.

Unfortunately, we did not have sufficient power to allow us to distinguish a threshold model from the predicted curvilinear model. From the graph of the proportion of females with palpation-provoked symptoms versus quintiles of knee extensor strength, it did appear that the proportion of symptomatic females was highest in the mid-range for strength. However, it was not possible to determine whether females with moderate weakness were truly at higher risk for shoulder symptoms than profoundly weak subjects or whether this peak was simply due to random error.

In terms of predicting resistance symptoms, we were not able to draw any definitive conclusions. While it does appear that some aspect of lower extremity strength is a significant predictor for resistance symptoms for both genders, the results were variable between KNEES, HIPS and ALL, depending on which genders were included in the model. The results for males suggested that knee extensor strength is more important. However, for females the results were not as clear and there remains some doubt as to whether hip extensor, knee extensor strength, or some combination of both is the best predictor for females. Because of the high correlations between strength variables, a larger study is needed to determine which aspect of lower extremity strength is most important when predicting resistance symptoms and whether there are actually any gender-related differences.

Shoulder abduction strength was not found to be a significant predictor of shoulder symptoms in this population. Shoulder flexion strength met the cutoff criterion in the univariate analysis for palpation symptoms among females (p-value = 0.150), but was not selected in the stepwise multivariate analysis. Previous research on other populations has shown a relationship between weak shoulder muscles and shoulder symptoms in able-bodied adults (abductors and external rotators) [18] and in wheelchair athletes (adductors and internal rotators).[19,20] It is possible

that other shoulder strength measures such as adductor or internal rotator strength, which were not measured in this study, are related to shoulder symptoms in this population. However, despite this, the fact that knee extensor strength was a good predictor of shoulder symptoms provides support for our hypothesis that lower extremity weakness plays an important role in the production of shoulder symptoms in this population.

Age was an important factor for predicting resistance symptoms. We had predicted that duration of time since polio would be more important than chronological age in this population, but duration was not significant even at the univariate level. We had also predicted that symptoms would increase as age increased. However, the results showed that the proportion symptomatic subjects was highest among the younger females and the middle-age males in our study population. We speculate that these age levels may be most closely associated with the activity levels that provoke the symptoms.

In able-bodied populations, repetitive manual work is a known risk factor for shoulder symptoms.[21,22] A previous study involving 32 polio survivors reported that the experience of pain was related to level of physical activity.[5] In this study, we expected that lower limb activity level or transfer activity level would be an important factor in predicting the presence of shoulder symptoms. However, none of the activity levels were significant at the univariate level for resistance symptoms and only upper limb activity level was significant at the univariate level for palpation symptoms (p-value = 0.033). One possible explanation is that our activity questionnaire provided us with only a gross measure of upper and lower limb activity. In order to cover individuals with a wide range of strengths and activity levels, we were forced to make our questions as broad as possible. If we had limited our study to individuals with significant lower extremity weakness and concentrated more closely on activities performed by people at

this strength level, we expect that we would have found a stronger association between activity level and shoulder symptoms.

Another limitation of this study was that we did not have the power to test interactions between independent variables due to the relatively low percentage of subjects with each symptom cluster. More data are needed in order to capture the complicated synergisms that may exist between variables. For example, we would expect that there would be an interaction between strength and weight. Previous studies have documented that the amount of muscle strength required to perform daily activities increases as weight increases.[23,24,25] Weight was an important predictor for palpation symptoms along with overall knee extensor strength. We attempted to capture the interaction between knee strength and weight by calculating the ratio between the two variables (knee extensor strength divided by weight). However, our analysis showed that this ratio did not predict the presence of palpation-provoked symptoms as well as the model with weight and KNEES.

Future studies are needed in this area involving larger samples to better characterize the shapes of the distributions of symptom risk. Research involving other populations with varying levels of lower extremity weakness is also needed to determine if these results are generalizable to other groups. For example, the elderly are at high risk for lower extremity weakness due to a reduction in activity level and the decline in muscle strength associated with normal aging. In a sample of 58 subjects with no history of any neuromuscular disorders, aged 60 to 88 years, we found that 39% had bilateral knee extensor strength that was less than 79 lb. (unpublished data). According to our model, these people may be at high risk for development of shoulder overuse symptoms.

Biomechanical studies of the compensation patterns used by people with lower extremity weakness are also needed, both to identify the specific activity patterns and to determine whether there are actual gender differences. Finally, there is a need for studies which examine the effectiveness of therapies designed to either reduce the stress on the shoulders or increase the strength of the lower extremities as a way of preventing or reducing overuse symptoms in the shoulder.

CONCLUSIONS

The results of the present study indicate that there is a relationship between lower extremity weakness and shoulder symptoms. In this sample of polio survivors, knee extensor strength was identified as an important predictor of shoulder symptoms, with individuals with moderate weakness at highest risk. Body weight and age were also relevant factors. These results have important implications for people with significant levels of lower extremity weakness, who tend to increase their reliance on the upper extremities for mobility and activities of daily living. For these people, shoulder overuse problems can have a significant effect on quality of life. Additional research is needed to increase the awareness of the prevalence and impact of upper extremity overuse disorders in people with lower extremity weakness.

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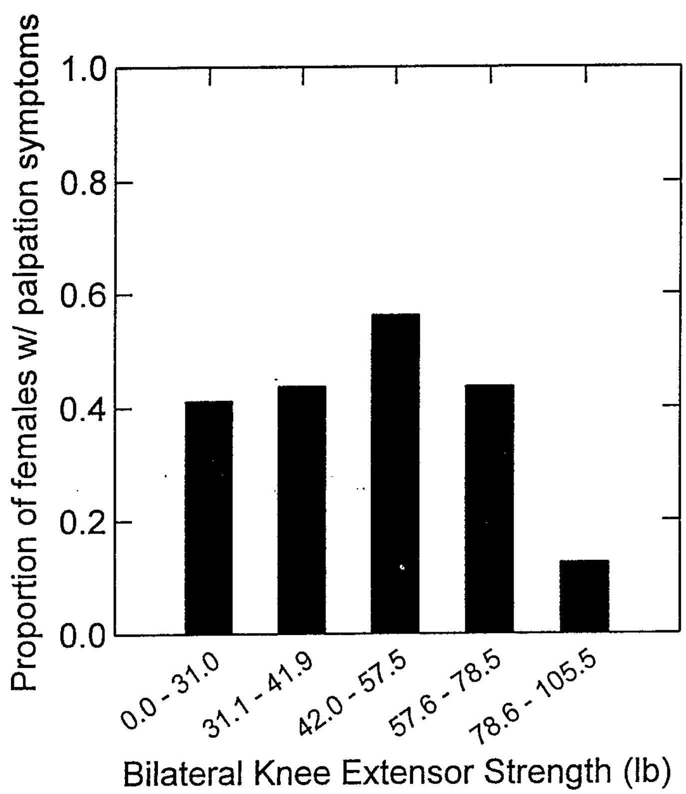
LEGENDS

Figure 1 illustrates the relationship between knee extensor strength and the proportion of females with Cluster 1 (palpation) symptoms. Quintiles of strength among females are shown along the X axis, arrayed from weakest to strongest. The proportion of women with palpation-provoked symptoms in each quintile is shown on the Y axis.

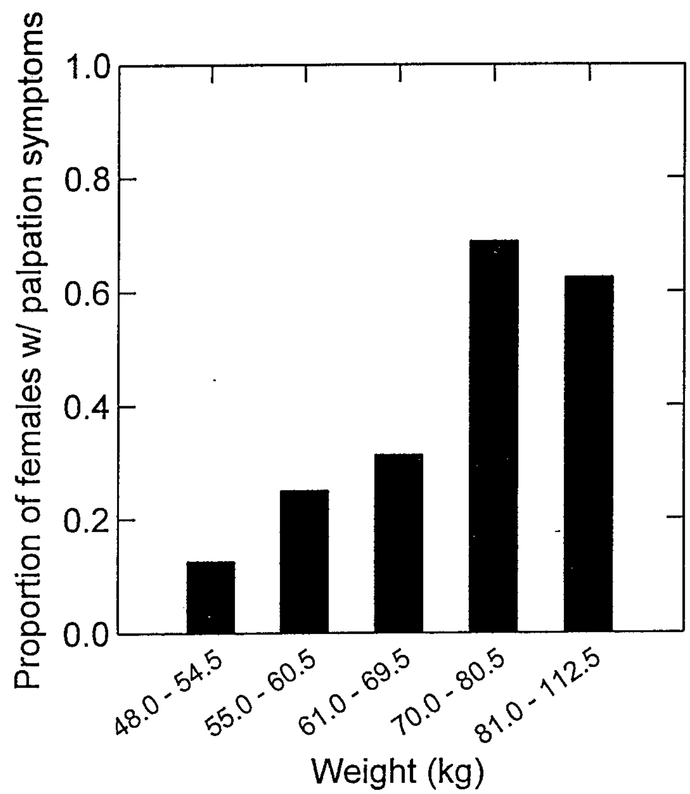
Figure 2 depicts the relationship between the proportion of females with Cluster 1 (palpation) symptoms and weight. Quintiles of weight, from lightest to heaviest, are shown on the X axis. The bars represent the proportion of women with Cluster 1 (palpation) symptoms in each quintile.

Figure 3 illustrates the relationship between overall leg extensor strength (ALL) and Cluster 2 (resistance) symptoms. The quintiles of strength are arrayed from weakest to strongest along the X axis, and the proportion of subjects with resistance-induced symptoms in each quintile is shown on the Y axis.

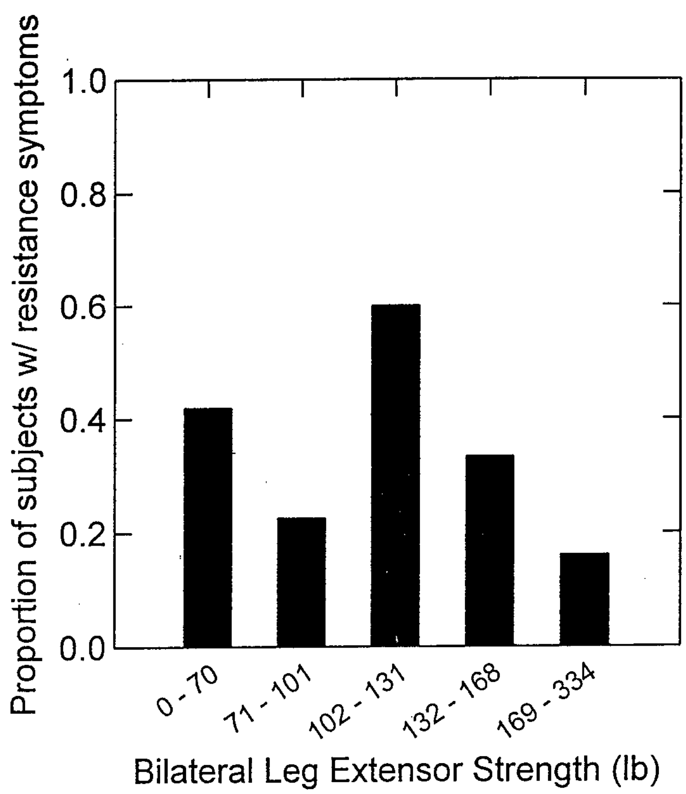
Figure 4 illustrates the relationship between age and Cluster 2 (resistance) symptoms. The quintiles of age are ordered from youngest to oldest along the X axis. The bars represent the proportion of subjects in each quintile with resistance-induced symptoms.



Proportion of females w/ palpation symptoms
1.0
0.8
0.6
0.4
0.2
0.0
0.0 - 31.0
31.1 - 41.9
42.0 - 57.5
57.6 - 78.5
78.6 - 105.5
Bilateral Knee Extensor Strength (lb)



Proportion of females w/ palpation symptoms
1.0
0.8
0.6
0.4
0.2
0.0
48.0 - 54.5
55.0 - 60.5
61.0 - 69.5
70.0 - 80.5
81.0 - 112.5
Weight (kg)



Proportion of subjects w/ resistance symptoms
1.0
0.8
0.6
0.4
0.2
0.0
0 - 70
71 - 101
102 - 131
132 - 168
169 - 334
Bilateral Leg Extensor Strength (lb)

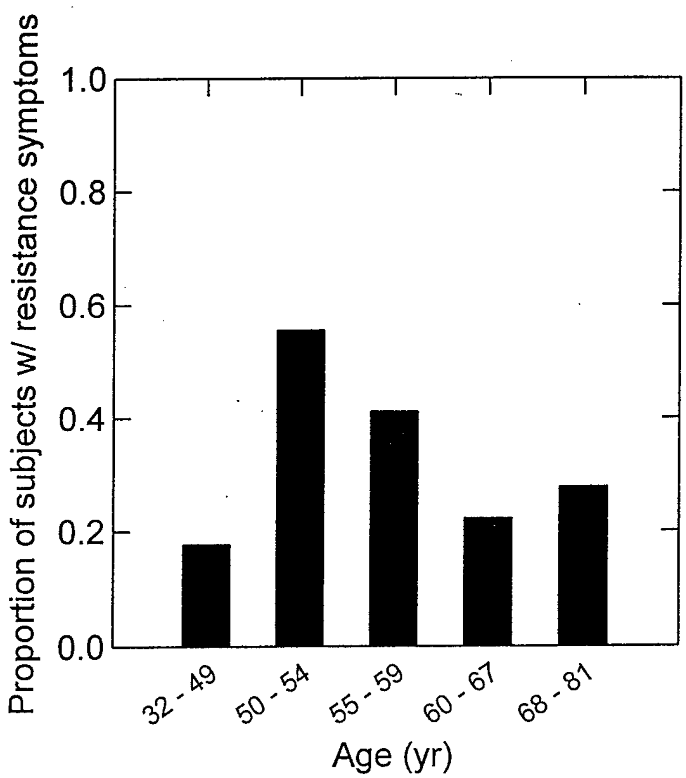

Proportion of subjects w/ resistance symptoms
1.0
0.8
0.6
0.4
0.2
0.0
32 - 49
50 - 54
55 - 59
60 - 67
68 - 81
Age (yr)

Table 1. Symptom Evaluation Protocol

Test	Arm Position	Procedure
Biceps palpation	Shoulder in neutral rotation; elbow flexed 90°; forearm supinated	Pressure applied in bicipital groove on anterior shoulder
Supraspinatus palpation	Arm relaxing at side;	Pressure applied on tendon insertion site just proximal to greater tuberosity of humerus
Supraspinatus (impingement) test	Arm straight out at side and internally rotated with thumb pointing towards floor	Examiner pushes on arm above elbow while subject resists
Biceps test	Shoulder in neutral; elbow flexed 90°; palm down	Examiner attempts to supinate forearm while subject resists

Table 2. Prediction of Shoulder Symptoms Provoked by Palpation

			Confidence Interval	
Variable*	p-value	Odds Ratio	Upper	Lower
Constant	0.000			
Weight	0.000	2.346	3.668	1.500
Knees - 1	0.014	13.454	107.589	1.683
Knees - 2	0.020	11.412	88.756	1.467
Knees - 3	0.006	18.526	146.600	2.341
Knees - 4	0.055	6.885	49.428	0.959

*.variables are in quintiles

Table 3. Prediction of Shoulder Symptoms Provoked by Resistance Tests

			Confidence Interval	
Variable*	p-value	Odds Ratio	Upper	Lower
Constant	0.001			
All - 1	0.052	5.833	34.436	0.988
All - 2	0.376	2.308	14.717	0.362
All - 3	0.044	5.250	30.621	0.900
All - 4	0.065	6.000	34.317	1.049
Age - 1	0.442	1.634	5.709	0.467
Age - 2	0.036	3.916	13.988	1.096
Age - 3	0.985	1.012	3.787	0.271
Age - 4	0.185	2.337	8.215	0.665

* variables are in quintiles

Table 4. Comparison of Regression Models

Model: KNEES and AGE

	Males	Females
Variable*	**Odds ratio**	Odds ratio
KNEES-1	**7.269**	5.549
KNEES-2	**3.952**	2.235
KNEES-3	**22.218‡**	4.838
KNEES-4	**2.095**	4.870
AGE-1	**2.154**	1.567
AGE-2	**16.396‡**	3.399
AGE-3	**11.759†**	0.310
AGE-4	**3.732**	1.215
Sensitivity	**0.758**	0.449
Specificity	**0.507**	0.693

Model: HIPS and AGE

	Males	**Females**
Variable*	Odds ratio	**Odds ratio**
HIPS-1	3.995	**10.032†**
HIPS-2	2.798	**2.860**
HIPS-3	3.819	**5.793**
HIPS-4	1.446	**6.406†**
AGE-1	0.855	**2.845**
AGE-2	3.979	**3.641**
AGE-3	4.050†	**0.395**
AGE-4	1.245	**1.863**
Sensitivity	0.435	**0.441**
Specificity	0.702	**0.725**

Note: The models which resulted from the stepwise multivariate analysis are in bold.

* - variables are in quintiles

† - $p < 0.05$

‡ - $p < 0.01$

TABLE 1. SUMMARY OF POST-POLIO RESEARCH

Authors	Population	Length of Study	Muscle(s)	Results
Dalakas et al.(1986)[1]	27 polio survivors* (symptomatic)	ave. of 8.2 yr. (range 4.5 - 20 yr.)	overall body score	annual decline of 1% in mean score
Munsat, Andres, and Thibideau (1987)[5]	6 polio survivors (symptomatic)	400 to 2100 days	unknown	no significant change in strength
Agre and Rodriquez (1990)[6]	23 polio survivors* 12 controls	2 yr.	biceps, hamstring, quadriceps	no significant change in any variables for either group
Agre and Rodriquez (1991)[7]	44 polio survivors* 38 controls	1 yr.	quadriceps (affected side only¶)	no significant change in any measures for either group
Munin et al. (1991)[9]	7 polio survivors* (symptomatic)	3 yr.	quadriceps	29% increase on affected side, 14% increase on the nonaffected side
Grimby, Hedberg, and Henning (1994)[2]	20 polio survivors* (12 unstable and 8 stable)	4-5 yr.	quadriceps and hamstring (affected side only¶)	significant decrease in all measures for unstable group; only for knee flexion in stable group
Agre et al (1995)[3]	78 polio survivors*	4 yr.	quadriceps and hamstring (affected side only¶)	significant decrease in quadriceps strength only
Grimby, Kvist, and Grangard (1996)[4]	18 polio survivors*	4 yr.	quadriceps, hamstrings in 26 legs	total thigh muscle strength decreased 7.8% $\pm$ 2.9%
Ivanyi et al. (1996)[10]	56 polio survivors* (43 symptomatic and 13 asymptomatic)	ave. of 2.1 yr. (range 199 to 1070 days)	Shld. abductors and adductors; Elbow flexors and extensors; Wrist flexors and extensors; Hip abductors, adductors, and flexors; Knee flexors and extensors; Ankle dorsiflexors and plantarflexors	significant increase in strength in 10 out of 22 muscles for symptomatic group; significant decrease in 1 out of 22 muscles for asymptomatic group
Rodriquez, Agre, and Franke (1997)[8]	23 polio survivors* (11 unstable and 12 stable) 14 controls*	7 years	quadriceps (affected side only¶)	no significant difference in rate of strength loss between groups

* - all subjects were less than 65 years old at initial visit
¶ - if both legs affected, stronger one was tested

Table 2. Strength Testing Protocol

Muscle Group	Body Position	Position of Limb	HHD Placement	Stabilization Point
Shld. Ext. Rotation	Sitting	Shoulder at neutral; elbow flexed 90°	Just proximal to ulnar styloid	Contralateral shoulder
Shld. Abduction	Supine	Shoulder abducted 90°	Midshaft of humerus	Anterior aspect of shoulder
Shld. Flexion	Sidelying	Shoulder flexed 90°; elbow extended	Midshaft of humerus	Anterior aspect of shoulder
Shld Extension	Sidelying	Shoulder at neutral; elbow flexed 90°	Proximal to olecranon	Anterior aspect of shoulder
Elbow Extension	Sidelying	Shoulder at neutral; elbow flexed 90°	Proximal to ulnar styloid; dorsal surface of forearm	Shoulder
Elbow Flexion	Sidelying	Shoulder at neutral; elbow flexed 90°	Palmar surface of forearm; proximal to wrist	Shoulder
Wrist Flexion	Sitting	Shoulder at neutral; elbow flexed 90°	Dorsal aspect of hand	Forearm
Wrist Extension	Sitting	Shoulder at neutral; elbow flexed 90°	Palmar aspect of hand	Forearm
Hip Abduction	Supine	Hip abducted to 45°; with contralateral hip neutral	Proximal to superior pole of patella on lateral aspect of thigh	Hip
Hip Flexion	Sidelying*	Hip flexed to 30°; knee flexed 60°	Proximal to superior side of patella	Pelvis
Hip Extension	Sidelying*	Hip neutral; knee extended	Proximal to popliteal crease	Pelvis
Knee Flexion	Sidelying*	Hip flexed 10°; knee flexed 30°	Proximal to maleoli on posterior aspect of calf	Anterior aspect of femur
Knee Extension	Sidelying*	Knee flexed 45°	Proximal to malleoli on anterior aspect of tibia	Femur
Ankle D. Flexion	Supine	Hip, knee, ankle at 0°	Metatarsals	Tibia
Ankle P. Flexion	Supine	Hip, knee, ankle at 0°	Metatarsal heads	Tibia

* Leg positioned on raised powder board

Table 3. Characteristics of Subjects in Upper Extremity Group*

Variable	Male Subjects N = 32 Mean (SD)	Female Subjects N = 39 Mean (SD)
Present age (years)	57.84 (11.7)	56.31 (8.6)
Age (at onset of acute polio, years)	7.15 (6.3)	6.41 (6.5)
Height (cm)	175.40 (7.9)	162.19 (6.4)
Weight (kg)	86.77 (18.4)	70.07 (16.8)
Strength (at initial visit, lb)		
Left Shoulder External Rotator	20.23 (9.4)	15.70 (4.6)
Right Shoulder External Rotator	20.96 (7.8)	16.14 (4.8)
Left Wrist Flexor	23.06 (7.8)	16.50 (4.7)
Right Wrist Flexor	26.67 (6.4)	19.10 (5.0)
Left Wrist Extensor	26.69 (7.0)	17.92 (5.2)
Right Wrist Extensor	26.11 (6.7)	18.19 (5.8)
Left Shoulder Abductor	30.37 (13.1)	19.26 (6.2)
Right Shoulder Abductor	29.39 (13.3)	18.83 (6.6)
Left Shoulder Flexor	34.27 (14.3)	21.89 (5.5)
Right Shoulder Flexor	34.13 (12.0)	21.66 (6.8)
Left Shoulder Extensor	36.38 (13.3)	23.24 (6.0)
Right Shoulder Extensor	34.36 (12.2)	21.75 (6.7)
Left Elbow Extensor	31.50 (15.4)	23.67 (6.3)
Right Elbow Extensor	33.95 (8.6)	23.09 (6.8)
Left Elbow Flexor	44.19 (14.5)	28.53 (7.5)
Right Elbow Flexor	44.55 (12.4)	29.70 (9.3)

* Reasons for excluding subjects from upper extremity group: 26 subjects had pain during testing, 17 subjects were missing data for one or more muscle groups, and 6 subjects had initial strength equal to zero in one or more muscle groups.

Table 4. Effect Sizes for Upper Extremity Muscles

Muscle Group	Effect Size
Right Wrist Flexor	1.109
Left Shoulder External Rotator	0.794
Left Elbow Extensor	0.758
Left Shoulder Extensor	0.719
Right Elbow Extensor	0.694
Right Shoulder External Rotator	0.670
Right Shoulder Extensor	0.525
Left Wrist Flexor	0.496
Left Shoulder Abductor	0.455
Right Shoulder Flexor	0.455
Left Wrist Extensor	0.448
Right Elbow Flexor	0.444
Left Elbow Flexor	0.421
Right Shoulder Abduction	0.391
Left Shoulder Flexor	0.310
Right Wrist Extensor	0.222

Table 5. Characteristics of Subjects in Lower Extremity Group*

Variable	Male Subjects N = 30 Mean (SD)	Female Subjects N = 35 Mean (SD)
Present age (years)	57.93 (10.6)	54.80 (7.3)
Age (at onset of acute polio, years)	7.55 (6.2)	5.91 (6.2)
Height (cm)	177.10 (1.8)	163.14 (6.6)
Weight (kg)	84.17 (17.8)	71.10 (13.8)
Strength (at initial visit, lb)		
Left Hip Flexor	43.21 (13.8)	29.60 (10.3)
Right Hip Flexor	45.07 (13.1)	30.82 (10.2)
Left Hip Extensor	36.40 (11.7)	26.75 (8.9)
Right Hip Extensor	35.79 (11.6)	25.56 (8.4)
Left Hip Abductor	42.00 (13.0)	28.22 (8.6)
Right Hip Abductor	38.57 (12.4)	25.13 (7.7)
Left Knee Flexor	38.80 (16.1)	27.97 (11.5)
Right Knee Flexor	36.67 (13.2)	22.51 (9.7)
Left Knee Extensor	43.20 (20.7)	29.47 (13.1)
Right Knee Extensor	45.09 18.8)	32.01 (15.5)
Left Ankle Dorsiflexor	32.45 (15.1)	25.40 (10.8)
Right Ankle Dorsiflexor	25.72 (13.6)	21.77 (10.6)
Left Ankle Plantarflexor	42.25 (16.8)	35.17 (14.7)
Right Ankle Plantarflexor	39.10 (19.2)	29.56 (14.2)

* Reasons for excluding subjects from lower extremity group: 12 subjects had pain during testing, 13 subjects were missing data for one or more muscle groups, and 30 subjects had initial strength equal to zero in one or more muscle groups.

Table 6. Effect Sizes for Lower Extremity Muscles

Muscle Group	Effect Size
Left Ankle Dorsiflexor	1.050
Right Ankle Dorsiflexor	0.856
Left Knee Flexor	0.682
Left Hip Flexor	0.419
Right Hip Flexor	0.383
Right Knee Flexor	0.218
Right Knee Extensor	0.128
Right Hip Extensor	-0.024
Left Hip Abductor	-0.037
Left Hip Extensor	-0.083
Left Knee Extensor	-0.110
Right Hip Abductor	-0.130
Right Ankle Plantarflexor	-0.296
Left Ankle Plantarflexor	-0.368

Table 7. Comparison of Rate of Deterioration of Strength*
in Young and Old Polio Survivors
Mean (SD)

Muscle Group	Young Group (40-50 yr.) N = 18	Old Group (60-70 yr.) N = 17	Mann-Whitney U p-value
Lower Extremity**	-0.031 (2.9)	-0.999 (3.1)	0.317
Left Hip Flexor	-2.314 (4.4)	-1.858 (3.1)	0.621
Right Hip Flexor	-1.055 (5.3)	-2.785 (3.9)	0.249
Left Knee Flexor	-2.507 (2.3)	-1.590 (2.4)	0.248
Right Knee Flexor	-0.520 (2.6)	-1.460 (4.5)	0.756
Left Ankle Dorsiflexor	-4.337 (3.7)	-4.820 (4.2)	0.644
Right Ankle Dorsiflexor	-2.446 (2.0)	-3.592 (3.2)	0.310

* represented by robust slope calculated based on strength data from three visits
** average slope across all lower extremity muscles